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FULL LENGTH ARTICLE

Multifractal analysis of slacken surface in hydrocarbon molecules through fuel additives

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Abstract This paper investigates the effect of organic fuel additives (Bio-Glycerol) on fuel savings, emission reduction and extend engine life. Using this enzyme, a motor cycle is tested five times. The test report shows the reduction in the release of carbon monoxide (CO) and hydrocarbon upto 60%. The use of organic fuel additives in diesel vehicles for different periods of time reveals the reduction in air pollution by 55%. Finally, we have experimented scanning electron microscope (SEM) test for organic fuel additives with biodiesel. The SEM image shows the existence of molecules of hydrocarbons. The analysis elucidated the complex morphology of molecules of hydrocarbons in fuel additives with biodiesel. The hydrocarbon molecules are slackened and irregular as it refers to the fractal form. SEM Photograph images are analyzed by multifractal analysis. MFA (multifractal analysis) is carried out according to the method of moments, i.e., the probability distribution is estimated for moments which differ from $-150 < q < 150$ and the generalized dimensions are estimated from the log/log slope of the probability distribution for the respective moments over box sizes. Generalized dimensions $D(q)$ are attained for this box size range, which are capable of characterizing heterogeneous spatial slackened surface.

1. Introduction

Two decades ago, most of the air pollution was due to flaming of conventional fuel. But the environment has been changed considerably since then. The ever rising propagation of automobiles would specify that, if unrestrained, gaseous exhaust products could enlarge without limit. Air pollution is the contamination of the atmosphere and environment by the introduction of chemicals, particulate matter or biological materials. In today's world, vehicles play a major role in air pollution. The exhaust released by the vehicles as a result of combustion of fossil fuels contains minute carbon particles and various other poisonous gases. The use of petrol and diesel pollutes the air and is harmful to mankind, animals and plants. The chief pollutants of air are carbon monoxide, sulfur dioxide, nitrogen oxide, certain hydro carbons, lead and particulate matter. All these pollutants

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arise specifically from exhaust emission from motor vehicles, aeroplanes and chimneys of factories.

Gasoline and diesel engines used in on-road vehicles are a major cause of air pollution. Emissions from these vehicle engines increase the range of problems related to air, weather and human physical condition concerns [4]. The emission depends on a number of factors such as age of the vehicle, engine design and operating conditions, lubricant oil, fuel quality and environmental conditions [8].

Fuel additives are very useful to all vehicles with petrol and diesel engines as they reduce hydrocarbons, nitrogen oxide, carbon monoxide and particulate emission factor. Bio-organic fuel additives increase efficiency and competence of the fuels used in motor vehicles and increase the performance of their engines. There are numerous benefits related with the use of fuel additives. One of the major advantages is the engine performance.

Along with preventing buildup in the motor, fuel additives are claimed to also improve appropriate lubrication of working components. This particular advantage means less wear and tear on the moving parts, which translates into lower and less frequent repairs during the life of the car or truck. From this viewpoint, spending a little extra additive-infused gasoline or buying stand-alone additives can save a great deal of money over a period of several years.

We have introduced a non-hazardous fuel additive containing bio-organic compounds. Experimental based study on this fuel additive showed a good result for both human beings and the environment.

1.1. Applications of fractals

Fractals are categorized into three kinds based on similarities i.e., exact, quasi and statistical self-similarity. Statistical self-similarity – this is the weakest type of self-similarity; the fractal has numerical or statistical measures which are conserved across scales. In the real world we are more likely to encounter statistical fractals, where the rescaled parts have the same statistical properties as the whole object. It has been newly appreciated that concepts from fractal geometry may be used to describe the surface morphology and complexity of the surfaces. Fractals is one method of characterizing the heterogeneity on the surface. Fractals are disordered systems and the disorder is depicted by non-integral dimensions. The concept of fractal geometry has been provided an effective means of describing structures and processes in experimental systems [1]. In most cases, roughness of surfaces of different sizes is self-similar, which can be characterized by fractal and multifractal theories. In our experiment (scanning electron microscope) SEM images of hydrocarbon molecules are slackened and irregular as it refers to the fractal form. This means that the fractal analysis technique used in this study is an efficient tool for estimating the loosen surface of hydrocarbon molecules in biodiesel.

A simple fractal can only characterize an entire study of the target and cannot give complete and detailed information, but a multifractal can provide more detailed information than the simple fractal analysis. The concept of multifractal measurement was first introduced by Mandelbrot [7] in order to study several features in the intermittency of turbulence. The multifractality and its formalism were further developed by many other authors and applied in several fields of science: biology, geology, molecular physics, astronomy, etc. In the last few decades, the multifractals have very significant application in scanning electron microscope (SEM) images. The fractal concept has been applied to petrochemical based study by several researchers including Cai et al. [2], Jongil et al. [5], Maricq et al. [9], Olfert et al. [10] and Schmidt-Ott [12].

This paper is presented as follows. In Section 2, a quite concise introduction to the essentials of multifractal analysis is given. Investigations on the effect of organic fuel additives (Bio-Glycerol) and different test experiments are explained in Sections 3 and 4 respectively. The results of the multifractal technique and their corresponding SEM images of generalized fractal dimensions are presented in Section 5. The conclusion is addressed in the final Section 6.

2. Method

2.1. Multifractal analysis

The Renyi Entropies are important in Non-Linear Analysis and statistics as indices of uncertainty or randomness. They also lead to a spectrum of indices of Fractal Dimensions (Renyi Fractal Dimensions or Generalized Fractal Dimensions). Grassberger [3], Lakshmanan et al. [6] and Perrier et al. [11] systematically developed the multifractal theory which is based upon Generalized Fractal Dimensions (GFD). In this section, we describe the GFD Method for fractal images. We recall the classical definition of the Rényidimensions of order q, which are commonly used to characterize a multifractal object in a d-dimensional space.

Let us denote $p_i(\epsilon)$ the object density in any box i of size ϵ covering a part of the object:

$$p_i(\epsilon) = \frac{M_i(\epsilon)}{M} \tag{1}$$

where $M_i(\epsilon)$ is the mass of the object included in box i and M is the total mass of the object. The concept of generalized dimension $D(q)$ corresponds to the scaling exponents for the qth moment of the density.

They are defined as:

$$D(q) = \lim_{\epsilon \to 0} \frac{1}{q-1} \frac{\log \sum_{i=1}^{N(\epsilon)} p_i^q(\epsilon)}{\log \epsilon}. \tag{2}$$

where $N(\epsilon)$ is the number of boxes used to cover the object, and for $q = 1$ as:

$$D(1) = \lim_{\epsilon \to 0} \frac{\sum_{i=1}^{N(\epsilon)} p_i(\epsilon) \log p_i(\epsilon)}{\log \epsilon}. \tag{3}$$

In practice, the object density defined in Eq. (3) is taken to the respective power of q, summed for all i, and plotted versus the box size in a log-log coordinate system. From this slope, which is also called the mass exponent τ, the generalized dimensions are estimated as in $D(q) = \tau(q)/(1-q)$. In principle, the parameter q can be any number minus to plus infinity. However, the most common choices for q are 0, 1 and 2. They are called Fractal, Information and Correlation dimension respectively.

3. Procedures

3.1. Test experiment

The test experiment was first performed on petrol engine vehicles by adding 1ml of fuel additive to a liter of petrol. From

Table 1 Pollution control certificate.

S. No		Regulation/units	6.4.12	13.4.12	25.4.12	15.5.12	28.7.12
1	CO	3.5	3.99	3.41	2.17	1.89	1.41
2	HC	4500	3040	1060	1060	880	970

Table 2 Test report.

S. No	Tests	Requirement/limit	Without additive	With additive
1	Density	–	757.4 kg/m^3	752.2 kg/m^3
2	Lead	max 0.013	0.4	0.1
3	Reid vapor pressure	35–60	42 Kpa	43 Kpa
4	Sulfur content	max 0.05	0.016%	0.011%
5	Vapour Lock index	750	553	563

Table 3 Pollution control report details.

Date	21–24.4.12		5.5.12		23.5.12		Reduction–% age
S. No	Level	%	Level	%	Level	%	Overall reduction
HDV-1	2.01/2.45	82.04	1.98/2.45	80.82	0.97/2.45	39.59	48.26
HDV-2	1.79/2.45	73.06	1.12/2.45	45.71	0.91/2.45	37.14	50.84
HDV-3	1.75/2.45	71.43	2.04/2.45	83.27	1.01/2.45	41.22	57.71
HDV-4	1.63/2.45	66.53	1.6/2.45	65.31	0.89/2.45	36.33	54.60
HDV-5	2.04/2.45	83.27	2.03/2.45	82.86	0.92/2.45	34.75	40.20

Table 4 Test report.

S. No	Tests	Requirement/limit	Before additive	After additive
1	Ash	0.01	0.01	0.01
2	Density	–	0.8764	0.8762
3	Cetane index	min 46	54.27	52.06
4	Inorganic acidity	–	Nil	Nil
5	Kinematic viscosity	2–5	2.769 mm^2/s	2.749mm^2/s
6	Total contamination	–	1.2 mg/kg	1.30 mg/kg
7	Total acidity	–	0.53	0.51
8	Water content	–	76 ppm	72 ppm
9	Sulfur content	–	0.05%	0.02%

Table 1, the result revealed that the emission of carbon monoxide and hydrocarbon has reduced from 3.99 to 1.41 & 3040 to 970 respectively.

The reduction in the excessive emission of hydrocarbons and carbon monoxides is greatly attributed to the use of this fuel additive which also reduces air pollution. Also we have tested the petrol with fuel additives at Italab Private Limited, Chennai and the report is summarized in Table 2. This report indicated that major reduction of sulfur content and lead was due to the petrol with additive.

The test experiment was again performed on five heavy duty diesel vehicles (HDV) on three different dates by adding fuel additives of diesel. The pollution control report outcome pointed out 55% reduction in pollution as shown in Table 3. Also we have tested the diesel with fuel additives at SGS Private Limited, Chennai and the report is summarized in Table 4. This report indicated major reduction of cetane index and sulfur content.

The fuel additive plays a vital role in cleaning the carbon particles deposit in spark plug, piston rings and exhaust pipe. As the enzyme reduces the higher level of hydrocarbon molecules into lower level which enables easy combustion, there is no outcome of carbon monoxide. Finally, the SEM test was performed on biodiesel (Jatropha oil) with fuel additive at Nanoscience technology, Tamil Nadu Agriculture University, Coimbatore, India. The microstructures of the molecules were examined before and after additive tests at room temperature by SEM test.

The difference between the two surface images can be evidently seen from Fig.1. The SEM image Fig.1(a) shows the existence of molecules of hydrocarbons. SEM test images indicate that hydrogen and carbon are joined together (before additive). After adding fuel additive in biodiesel, it was found that the density of the fuel additive has become less due to the conversion of high level hydrocarbon molecules to low level hydrocarbon molecules. This indicated that eliminating carbon deposits on valves and pistons allows complete fuel combustion. It is clear that the hydrocarbon molecules are not broken by fuel additives, but they are slacken (become less tight) on the surface Fig.1(b).

4. Gas chromatographic analysis

The petrol engine vehicle is tested with fuel additives for seven days and the following results are obtained using a Gas chromatographic analyzer:

4.1. Carbon monoxide (CO vs Time)

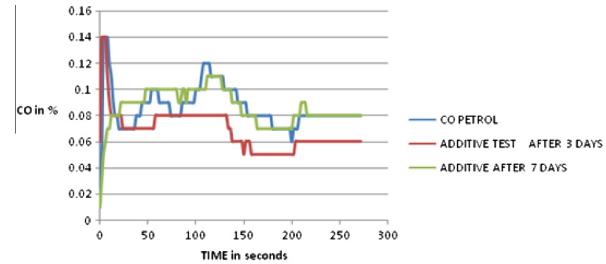
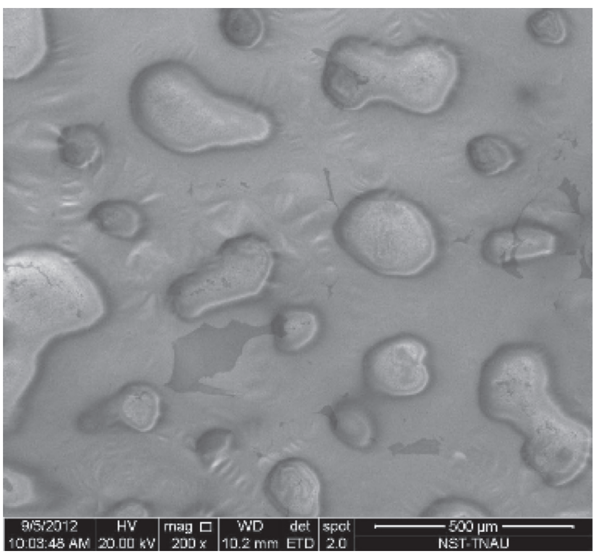
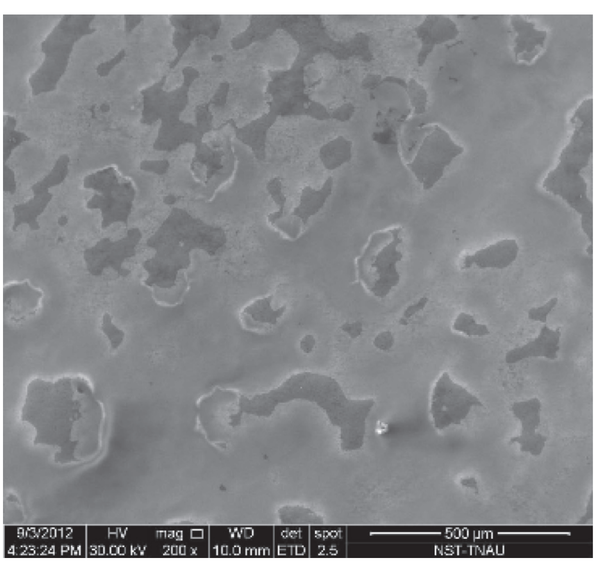


Figure 2 CO vs Time.

From the pictorial representation 2 (Fig. 2), it is clear that the usage of fuel additives has reduced the release of carbon monoxide from 0.14% to 0.06%. Regular usage of the additive certainly reduces the release of carbon monoxide to a greater extent.



(a)



(b)

Figure 1 The SEM image of biodiesel (a) before additive (b) after additive.

4.2. Hydrocarbon (HC vs Time)

Fig. 3 shows that the practice of fuel additives has reduced the discharge of hydrocarbon from 1200 ppm to 150 ppm.

4.3. Oxygen (O_2 vs Time)

Fig. 4 reveals that the usage of fuel additives has reduced the release of oxygen from 20% to 5%. The result indicated that intake of oxygen is increased.

4.4. Carbon di-oxide (CO_2 vs Time)

From Fig. 5, it is clear that the usage of fuel additives has increased the level of carbon di-oxide from 8% to 11%.

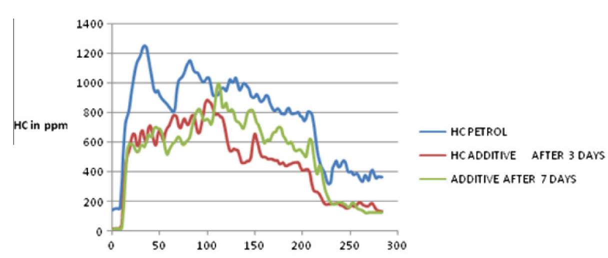


Figure 3 HC vs Time.

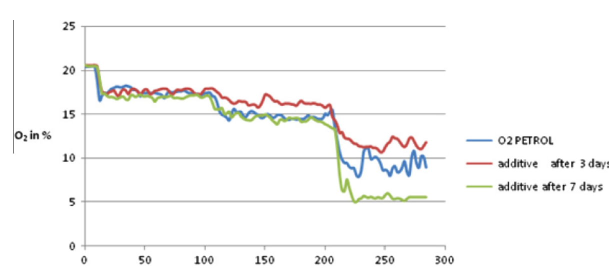


Figure 4 O_2 vs Time.

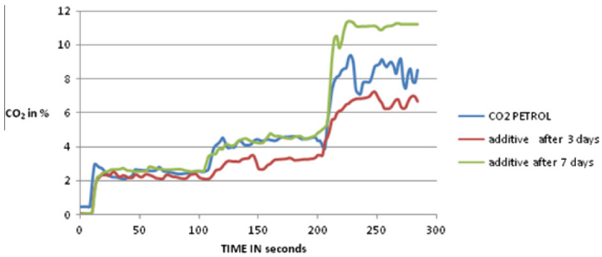


Figure 5 CO_2 vs Time.

Table 5 D_q versus q.

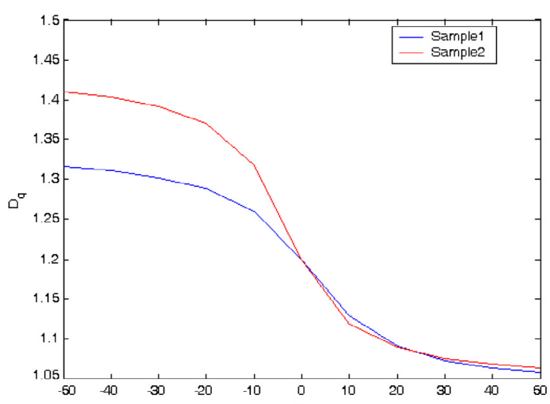
q	D_q	
	Sample 1 (before additive)	Sample 2 (after additive)
-50 to 50	1.3165	1.4102
-100 to 100	1.3288	1.4241
-150 to 150	1.3332	1.4292

5. Results

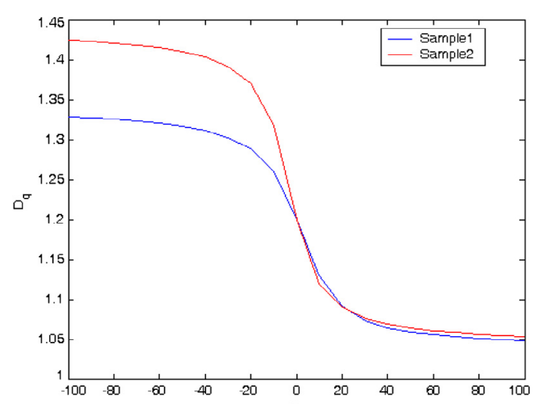
The computations in this section are performed through MATLAB Software. Multifractal parameters are used to obtain a quantitative explanation of SEM images. Multifractal analysis characterized and discriminated the two surfaces before and after adding the enzyme. Based on the results of computation, we have drawn the generalized fractal dimensions spectrum curve of the molecules of hydrocarbons using SEM images before and after adding the enzyme as in Fig.6 and the generalized fractal dimension values are listed in Table 5.

The generalized fractal dimension spectrum reflects the variation law of different probability measures. If $q < 0$, the small probability measure set will be reflected if $q > 0$, the large probability measure set will be reflected.

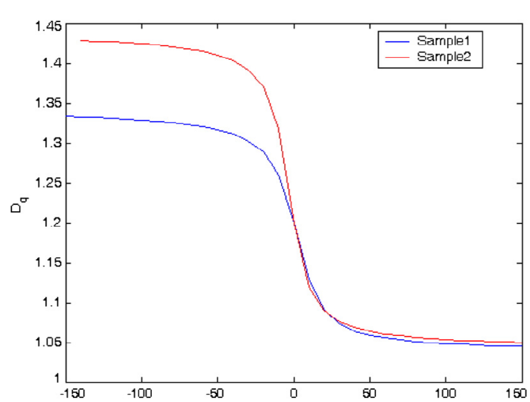
It can be seen from the figure, that before and after adding the enzyme the generalized fractal dimensions curve of the molecules of hydrocarbon surface structure is monotonically decreasing, and has an enormous change on both sides if $q = 0$. In the figure, the movement of the curve is relatively downward when $q > 0$, and the curve is steep when $q < 0$, which shows that the changes of small probability measure set increase the heterogeneity and complexity of the sample morphology. Also it is clear that before adding the enzyme, the D_q values are low for all the values of q which shows that the surface of the hydrocarbon molecules is homogeneous (sample 1). But after adding the enzyme, the D_q values are high for all the values of q which exhibits that the surface of the hydrocarbon molecules has slackened (sample 2).



(a) -50 to 50



(b) -100 to 100



(c) -150 to 150

Figure 6 Curves of generalized fractal dimension D_q versus q.

6. Conclusion

The multifractal analysis takes into account the result of the surface heterogeneity on the slacken surface of hydrocarbon molecules. The heterogeneity on the slacken surface has been made quantitative using generalized fractal dimensions D_q value. The result shows that molecules of hydrocarbons are slackened due to the addition of fuel additives. Using this fuel additive to vehicles eliminates carbon deposits on valves and pistons which allows complete fuel combustion. The reduction in the emission of hydrocarbons and carbon monoxides due to the use of this additive also reduces greenhouse gases. The use of fuel additives protects our environment, reducing exhaust pollution from all types of vehicles, cutting down CO (carbon monoxide), HC (hydrocarbon), nitrogen oxides and black smoke with particulate matter. The implementation of this fuel additive in new engines would definitely increase the life span of such engines. This would assist in cleaning the whole system together with nozzles of these engines. Also there is a drastic reduction in the emission of smoke, sound/noise and air pollution.

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References

[1] A.L. Barabasi, H.E. Stanly, Fractal Concepts in Surface Growth, Cambridge, 1995.
[2] J. Cai, C.M. Sorensen, Phys. Rev. E Stat. Nonlinear Soft Matter Phys. 50 (1994) 3397–3400.
[3] P. Grassberger, Phys. Lett. A 97 (6) (1983) 227–230.
[4] I. Gupta, R. Kumar, Atmos. Environ. 40 (14) (2006) 2552–2566.
[5] P. Jongil, Y. Jaehyuk, S. Soonho, M.C. Kwang, J. Aerosol Sci. 41 (6) (2010) 531–540.
[6] M. Lakshmanan, S. Rajasekar, Nonlinear Dynamics: Integrability, Chaos and patterns, Springer-Verlag, Heidelberg, 2003.
[7] B.B. Mandelbrot, Pure Appl. Geophys. 131 (1989) 5–42.
[8] M.M. Maricq, J. Aerosol Sci. 38 (11) (2007) 1079–1118.
[9] M.M. Maricq, N. Xu, J. Aerosol Sci. 35 (10) (2004) 1251–1274.
[10] J.S. Olfert, J.P.R. Symonds, N. Collings, J. Aerosol Sci. 38 (1) (2007) 69–82.
[11] E. Perrier, A.M. Tarquis, A. Dathe, Geoderma 134 (2006) 284–294.
[12] A. Schmidt-Ott, Appl. Phys. Lett. 52 (12) (1988) 954–956.